Sunpower Cooling Solutions

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ABSTRACT

Sunpower specializes in free-piston Stirling engines and cryocoolers, pulse tube cryocoolers, and free-piston linear compressors. Sunpower offers four different Stirling cryocoolers to meet varying performance, environmental and cost targets. All of Sunpower's cryocoolers are hermetically sealed, contain no HCFC's, and are designed for high performance with maintenance-free, long-life operation. Sunpower is also developing pulse tube cryocoolers as another option for cooling solutions. Single and multi-stage pulse tube cryocoolers are currently at the laboratory prototype level. Figure 1 shows the thermodynamic performance of each cryocooler discussed in this paper.

M77

The M77 is the first cryocooler designed and built by Sunpower. The first M77 was delivered to a commercial customer in 1992. At a price of approximately $40,000, the M77 is a low-cost cryocooler for clients such as NASA and other government and university laboratories. Sunpower has delivered about 100 M77s since 1992, and one M77 at Sunpower has run continuously over 18,000 hours.

The M77, not designed for mass production, is assembled in small quantities and is designed to lift 4W at 77K with 100W of input power. The M77 was space qualified by NASA and is currently flying on the RHESSI solar flare mission. The original schedule called for the Sunpower M77 to remain in space for less than six months. As of June 2003, RHESSI has been operational for 16 months.

M87

A company specializing in medical products approached Sunpower for the design and production of a long-life, commercially-priced cryocooler. The result, the M87, was an M77 offshoot redesigned for cost-reduction and manufacturability. In parallel to the development of the M87, Sunpower established a modern production facility currently capable of producing 500 cryocoolers per month, extendable to 2,000/month with modest additional investment. This facility is also capable of producing each of the models discussed here.

The M87 is designed for use in climate-controlled environments, providing 7.5W of cooling at 77K with 150W of input power. Sunpower has built approximately 180 M87s since 2000. One hundred of the current version of the design have accumulated 330,000 hours of run time since January 2001.

CryoTel^{CT}

At the end of 2000, Sunpower and linear compressor development partner LG Electronics identified a potential need in the telecommunications industry for a small, efficient, low-cost cryocooler. The two companies formed a strategic alliance with the primary goal of developing this product. The strategic alliance planned to capitalize on Sunpower's history of free piston Stirling cryocooler research and development and LGE's experience in large scale manufacturing of low-cost white goods. The outcome of the strategic alliance was the CryoTel^{CT}, which is based on the M87 but can provide 10W of cooling at 77K with 155W of input power.

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The environmental operating range of the CryoTel^{CT} was extended to meet the needs of the telecommunications industry and can operate in ambient temperatures between -40°C and +60°C. The CryoTel^{CT} was also designed to be able to operate in any physical orientation without affecting cooling performance or reliability.

Sunpower has built more than 100 CryoTel^{CT} units since 2002. The design is ready for pilot production in the Sunpower manufacturing facility. The CryoTel^{CT} is designed to have a minimum operating life of five years. The next focus will be to implement an accelerated life test to establish the Mean Time To Failure (MTTF) and uncover any potential reliability issues with the CryoTel^{CT}. Due to the increased performance and low cost, the CryoTel^{CT} may eventually replace both the M77 and the M87.

CryoTel^{MT}

The CryoTel^{MT}, a smaller version of the CryoTel^{CT}, is the newest cryocooler model from Sunpower. The CryoTel^{MT} can operate across the same range of ambient temperatures as the CryoTel^{CT} and can lift 6W at 77K with 100W of input power. A manufacturing test run of the CryoTel^{MT} is currently underway and will be completed during the summer of 2003. The CryoTel^{MT} has the same efficiency and reliability expectations as the CryoTel^{CT}.

Pulse Tube

In addition to the line of Stirling coolers produced by Sunpower, single and multi-stage pulse tube cryocoolers (PTCs) are also under development as potential Sunpower products. The funding for PTC development came largely from Small Business Innovative Research (SBIR) funding from NASA Goddard Space Flight Center. In pursuit of this work, Sunpower partnered with David Gedeon of Gedeon Associates for his expertise in modeling and analysis of PTCs. Gedeon is the author of the commercial modeling software Sage and Sunpower is an industry leader in the design and production, including manufacture, of linear compressors. This combination of expertise in linear compressors and PTC analysis led to the succesful development of one single-stage PTC prototype and one two-stage PTC prototype.

Sunpower constructed both inline and u-tube configurations of the single-stage PTC. The u-tube configuration allows for more convenient packaging of the cooler and easier addition of multiple stages. The inline cooler was integrated, meaning the cold head was attached directly to the compressor. In the u-tube and two-stage configurations, the cold head was separated from the compressor by a connecting tube. These design features are flexible depending on the requirements of the customer. Acoustic tuning in all configurations was accomplished by an inertance assembly rather than an orifice or double inlet PTC. As part of the development program, a cost study of the single-stage u-tube configuration was performed. This study showed that the cost of the components was very similar to the cost of components in the Sunpower M87 Stirling cooler. Depending on the cost of assembly and processing, this information suggests that the single-stage PTC should be cost competitive with Sunpower's line of Stirling coolers in production volumes.

Technical advancements under internal funding from Sunpower have actually boosted the performance achieved at the end of the SBIR development program by 25%. The single-stage inline PTC is currently capable of 6W of lift at 77K with 100W input power. The two-stage prototype achieved 260 mW of cooling at 30K, with 100W input power and the first stage unloaded at 80K. The single and two-stage pulse tube technologies at Sunpower are ready to take the next step toward commercial development. Sunpower is currently seeking funding for such development.

Currently, under additional NASA Phase II SBIR funding Sunpower is building a prototype three-stage PTC for cooling below 10K. The program will end in January 2004. Initial performance of the three-stage PTC will be presented at the CEC/ICMC conference to be held in Anchorage, Alaska in September 2003. The three-stage PTC also promises potential for a commercial product at Sunpower.

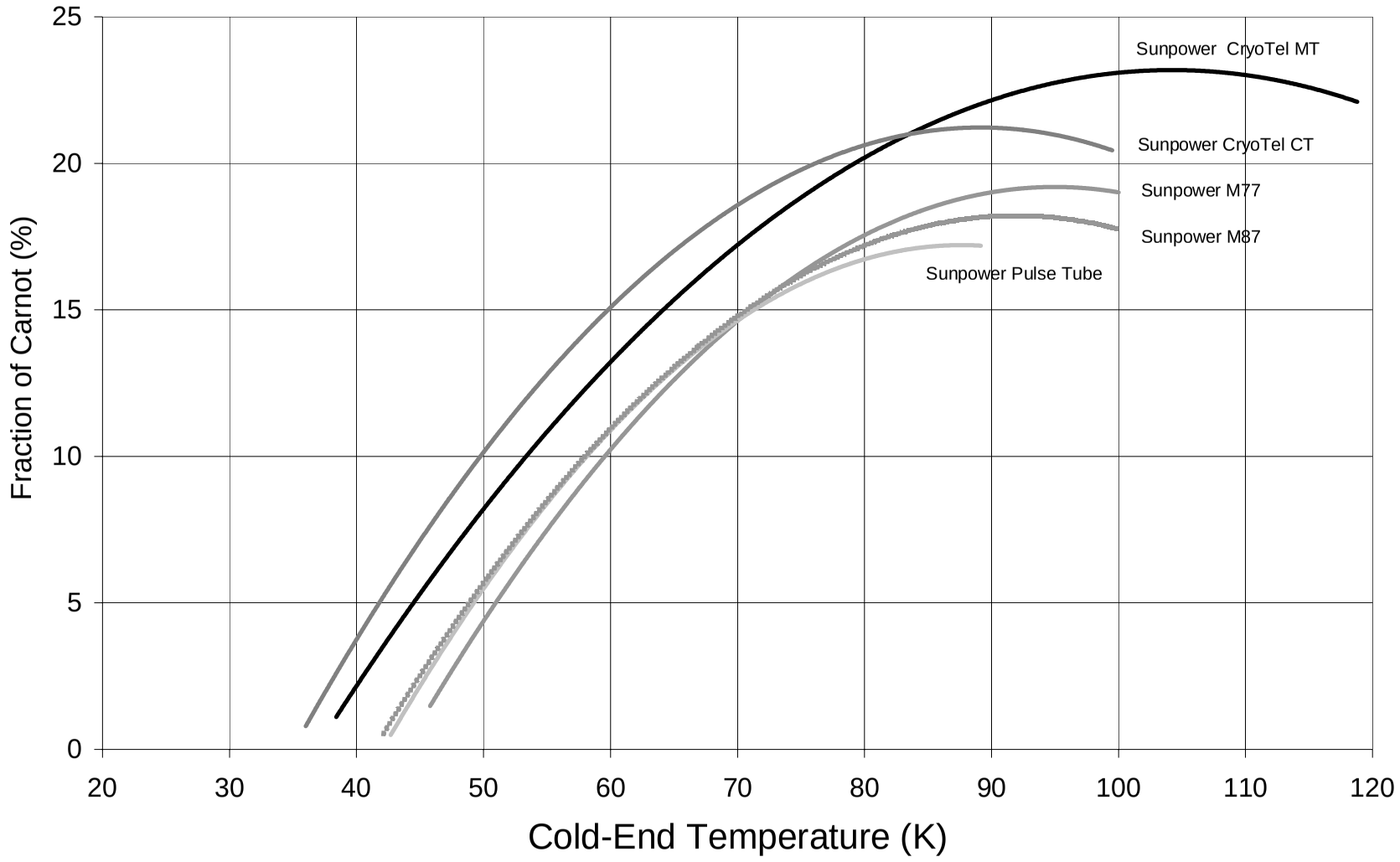

Figure 1: Sunpower Cryocooler Thermodynamic Performance